Repeatability and reliability of fracture trace analysis,

and the use of Multiple Analysis Sources with Independent Validation to add confidence to fracture trace analysis results.

By Ethan O. Weikel, P.G.

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From Science to Solutions
1129 Business Parkway South,
Suite 10, Westminster, MD 21157
Ph: 410.876.0280 fax 410.857.5535

Introduction

- Fracture trace analysis, and specifically lineament trace analysis, involves the identification of lineaments in aerial photo stereography, appropriate satellite imagery, and other data sets such as aeroradioactivity, LiDAR, SLAR, et cetera.

- Identified lineaments may be weighted, prioritized and field checked in order to add confidence to the results.

- It is a recognized analytical tool used by hydrogeologists, geoscientists, & engineers for siting wells and wellfields, locating springs and wetlands; siting monitoring wells in aquifers dominated by fracture flow; intercepting pollutants for aquifer restoration; and characterizing the state and nature of bedrock and surficial deposits for foundation and slope stability investigations, and related geotechnical projects (stability in mines, tunnels, landfills, and dam sites).

Background

- The theory and techniques of fracture trace analysis have been around for well over a hundred years, with large folios published as early as the 1900s. (Hobbs, 1903).
- Beginning the late 1950s there were a number of publications that highlighted issues with fracture trace analysis, specifically with topographic and photogeologic datasets as sources.
- And with the advent of additional remotely sensed data sources, a number of publications were produced in the early 1980s, e.g. Wise, 1982, which went into great detail about the problems inherent in fracture trace analysis methods.

Background (cont.)

- Even with improvements in speed and analytical efficiency brought about by modern computing, and additional data types produced by modern technology, the basic methods of fracture trace analysis have not greatly changed, and are used by professionals across the country for the assessment and other investigative applications.

- Studies of the repeatability of fracture trace analysis even among qualified geologists, with the same source data sets and agreed upon methods for analysis, indicate that results are often not in agreement.

- This is concerning but perhaps not surprising.

Background (cont.)

- One study (Short, 2007) documented an analysis performed by four NASA geologists in which they each performed a fracture trace analysis with the same data source and methodology which resulted in an agreement of the analysis performed independently by each geologist of 0.5 percent. This may be an extreme case since we are comparing the results of all four, albeit well-qualified, geologists.
- There is a historic study, widely referred to but never referenced, in which a repetition of a fracture trace analysis by a geologist one year after his original analysis was in agreement by less than 50 percent.
- This raises serious concerns about reproducibility.

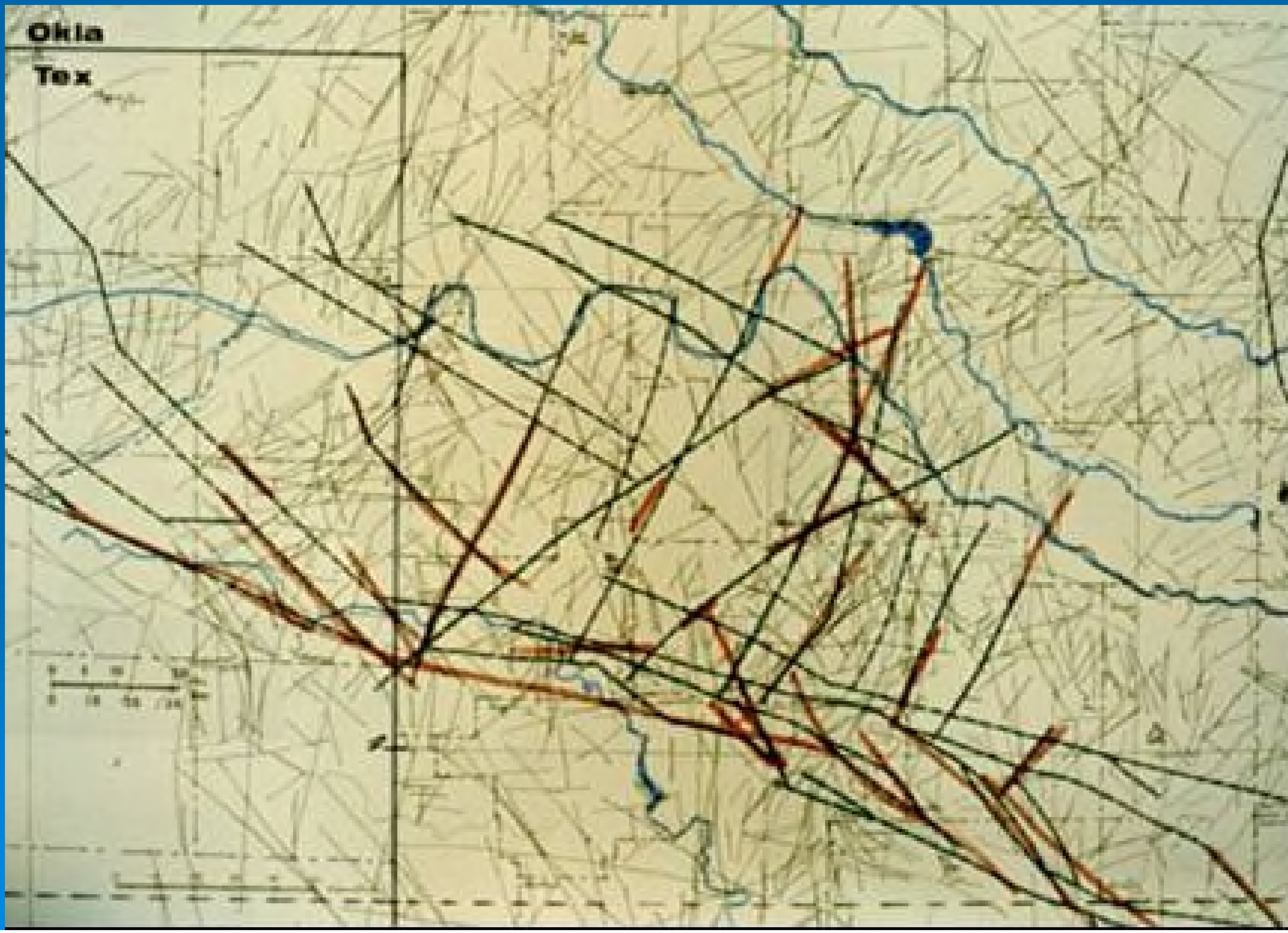
Case Study 1

- As referred to previously, Dr. Nicholas Short a former geologist at the NASA Goddard Space Flight Center documented a study from the early 1980s during his days at NASA Goddard in Code 923 (Short, 2007) on the reproducibility of lineament trace analysis.

- The study focused on one of the first uses of LandSat data, a pilot study conducted by Eason Oil Corp. and Earth Satellite Corp. of Rockville, MD in the Anadarko Basin of south-central Oklahoma where there are few structural indicators in the flat-lying sediments which overlie older folded units and where there is overprinting of geologic features by vegetation and land use.

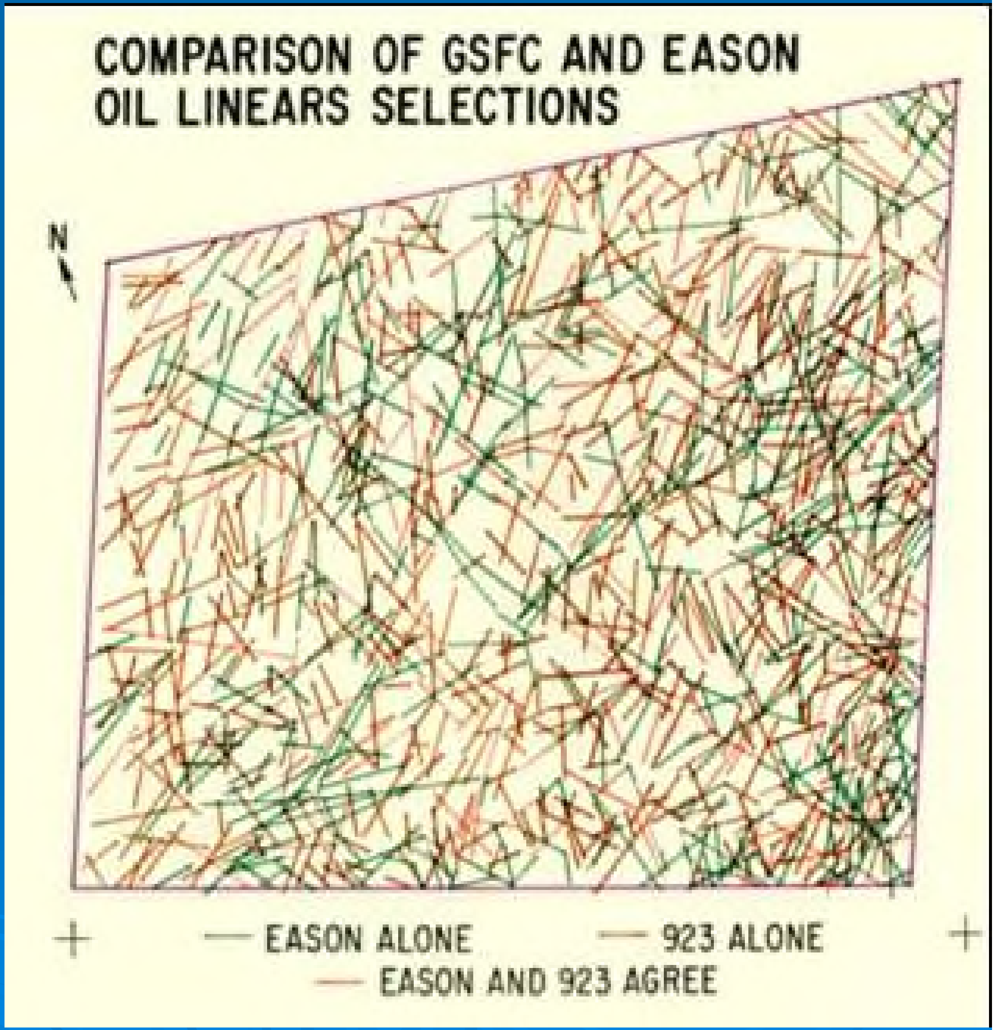
Case Study 1 (cont.)

- The results of the pilot study are shown below.



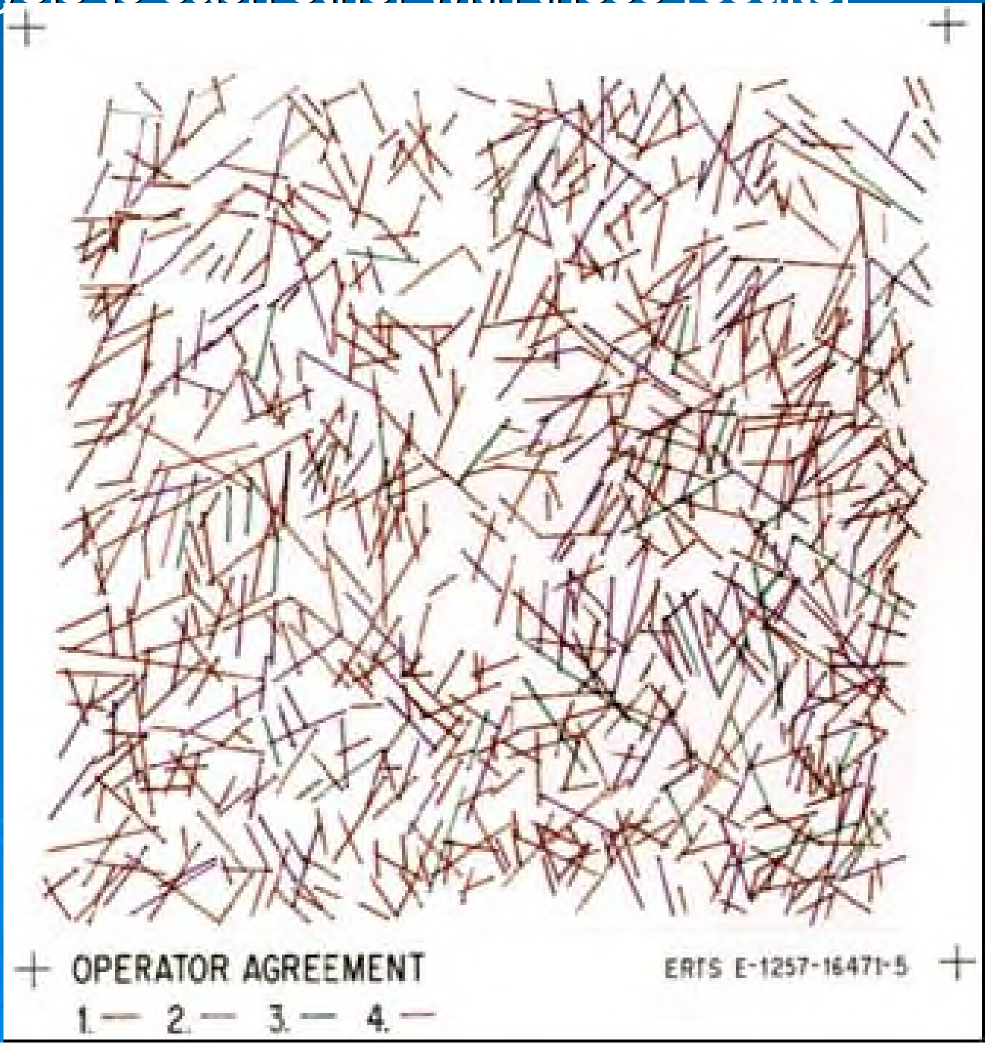
Case Study 1 (cont.)

- Four NASA Goddard geologists, including Dr. Short, took the same 1973 LandSat scene and using an agreed upon methodology each independently performed a lineament trace analysis. Afterwards they combined the four geologists' results. The comparison of the NASA Goddard Code 923 and Eason Oil Co. results are shown.



Case Study 1 (cont.)

- Analysis of the NASA Goddard Code 923 and Eason Oil Co. results reveal a 20% agreement. This was somewhat alarming and so the four NASA geologists compared their own analysis to each other with these results.
- The four geologists identified 785 features total.
- Only four features or 0.5 percent were identified by all four.
- 37 features or 4.7% were identified by at least three.
- 140 features or 17.8% were identified by at least two.
- The remaining 604 or 77% were identified uniquely.



Case Study 1 (cont.)

- This study noted that these results were not uncommon, however discouraging. Each geologist had ample experience in photointerpretation and special skills in analyzing LandSat Imagery.
- Dr. Short noted that there is “considerable subjectivity in deciding whether a given linear feature a) really exists, b) is geological in nature, and c) means anything”.
- He also noted that if the identified lineaments were plotted on rose diagrams and filtered with respect to the regional fracture orientations (using observed predominant trends as a domain for analysis) that this should reduce the number non-geological features.

Case Study 1 (cont.)

- Subsequent field checking of about 200 features selected using the filtering just mentioned revealed that only 20% were non-geological in nature.
- This evidence supports refinement of identified lineaments based on domain analysis such as observed dominant regional orientation.
- It is also noted in the study that the results of lineament analysis with this data source should be combined with other indicators.

Case Study 2

- The second case study (Johansson, 2005) was performed by the Geological Survey of Sweden (Sveriges Geologiska Undersökning or SGU) for Swedish Nuclear Fuel and Waste Management Co. (Svensk Kärnbränslehantering AB or SKB). In this study, a comparison of lineament trace analyses utilizing multiple data sources was performed by the SGU. The analyses were performed for the Forsmark site in Sweden, the location of a deep repository for high level radioactive waste.
- GeoVista AB was commissioned by SKB to perform extensive lineament interpretation as part of the site investigation, regional study, and feasibility study. Because of the importance of the results and the documented uncertainty in this type of interpretation, the Geological Survey of Finland (GTK) was asked perform an independent lineament trace analysis. The SGU study compares the two.

Case Study 2 (cont.)

- The GeoVista interpretation covered a larger area but the comparison focused on the area that overlapped with the GTK interpretation. GeoVista had more site specific knowledge, however the SGU assessment did not aim to address the quality of the interpretations, just the resulting analysis.
- GeoVista's interpretation was compiled from independent analysis of the following data sources:
- -High resolution topography and land cover
- -Airborne geophysical data (magnetic, dipole source EM, and VLF EM)
- -Seismic surveys

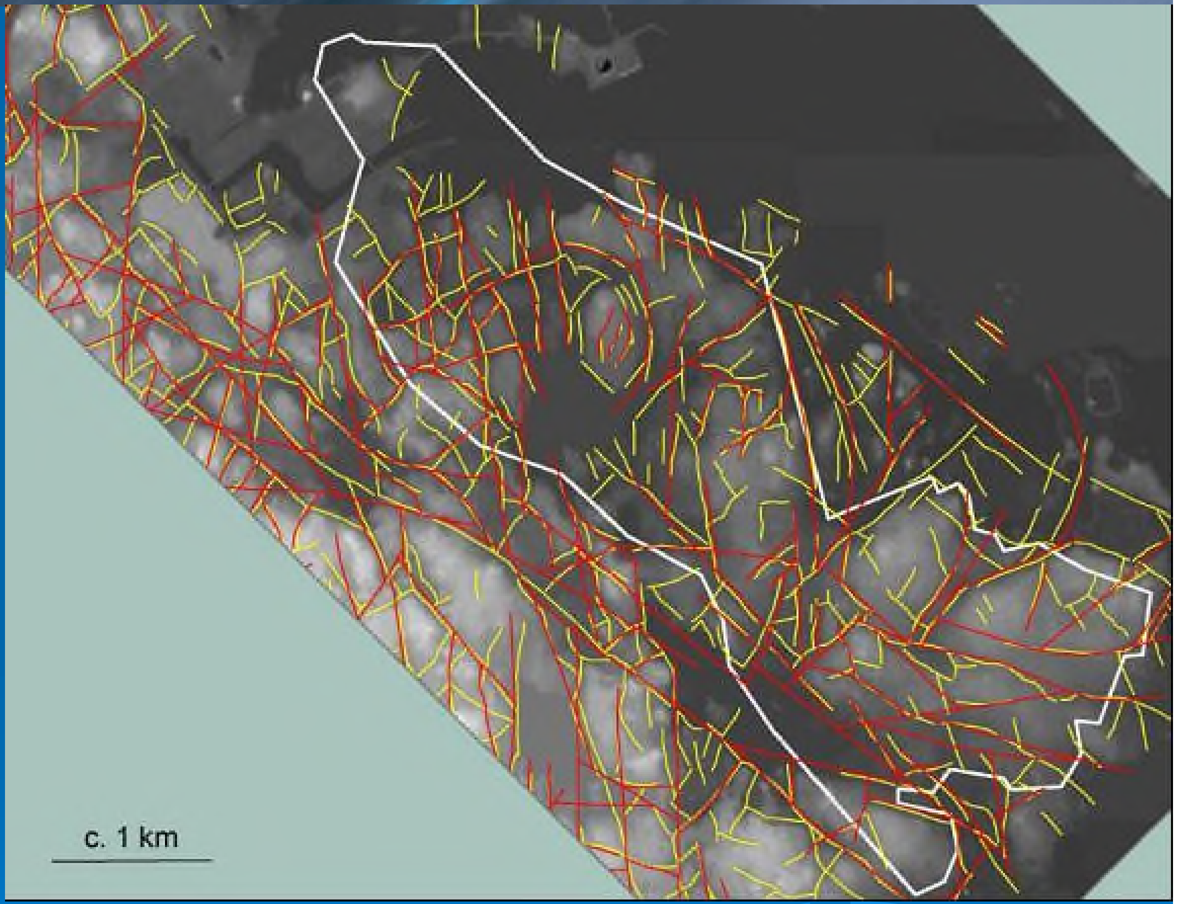
Case Study 2 (cont.)

- The results from independent analysis of these data sources were then fully integrated by GeoVista to represent a complete lineament trace interpretation for the Forsmark area. It should be noted that additional interpretation was prepared by GeoVista but not included in the SGU comparison due to classification and availability issues.

- GTK performed a lineament trace analysis with the same set of data sources used by GeoVista for this comparison and was instructed to use the same methodology.

Case Study 2 (cont.)

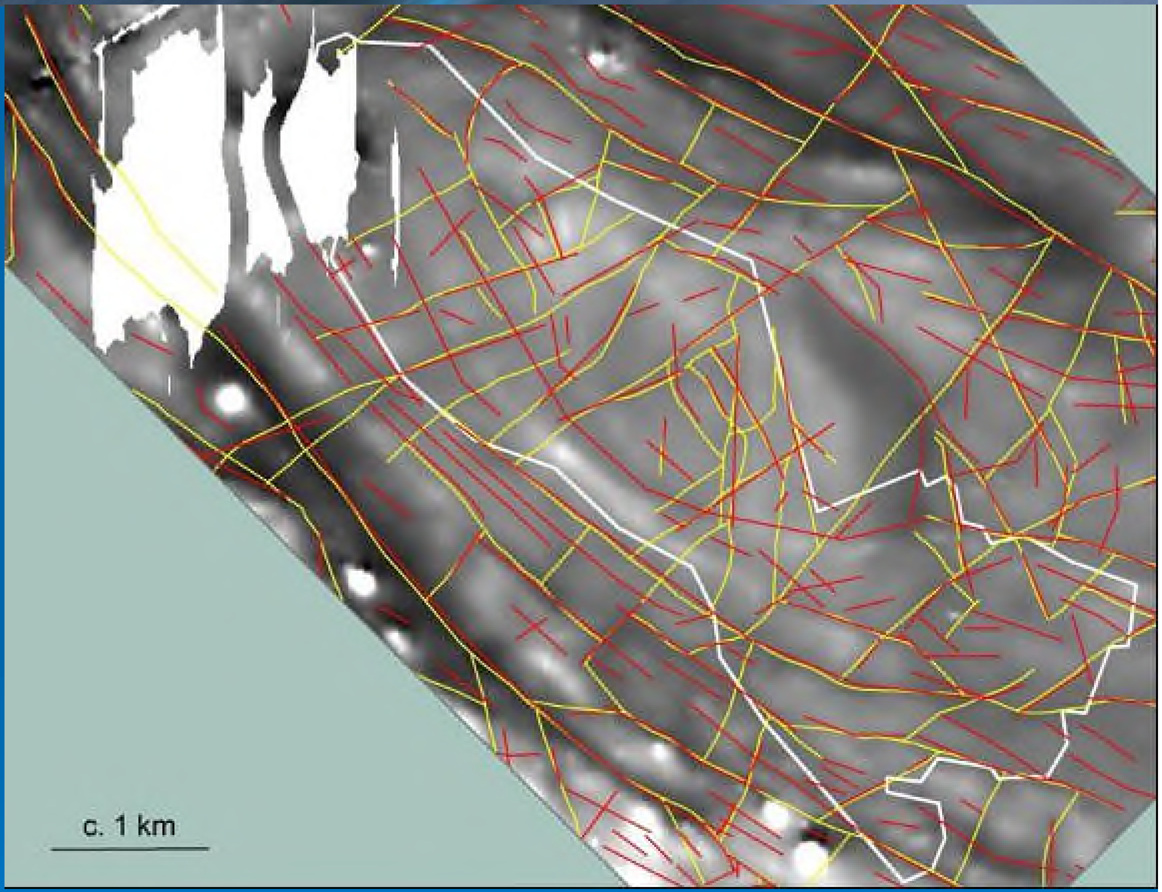
- Interpretation from high resolution topography and landcover overlaid on grayscale DEM:
- The GeoVista interpretation (yellow) includes far more lineaments overall than GTK's (red) which could be due to the greater amount of time spent by GeoVista on the interpretation.



- The critical point is that most of lineaments identified by GTK correspond to ones identified by GeoVista.

Case Study 2 (cont.)

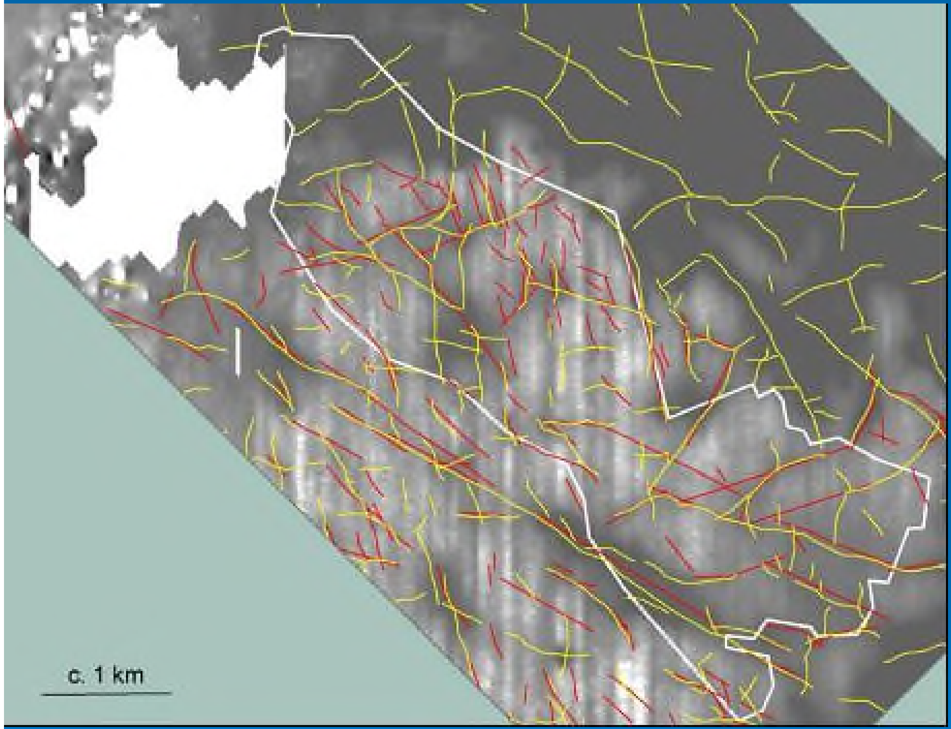
- Interpretation from magnetic data overlaid on grayscale magnetic anomaly representation:
- The interpretations by GeoVista and GTK from this data source are notably different at the outset, however if GTK interpreted lineaments less than 1km long are ignored then again there is a high degree of agreement between the two interpretations.



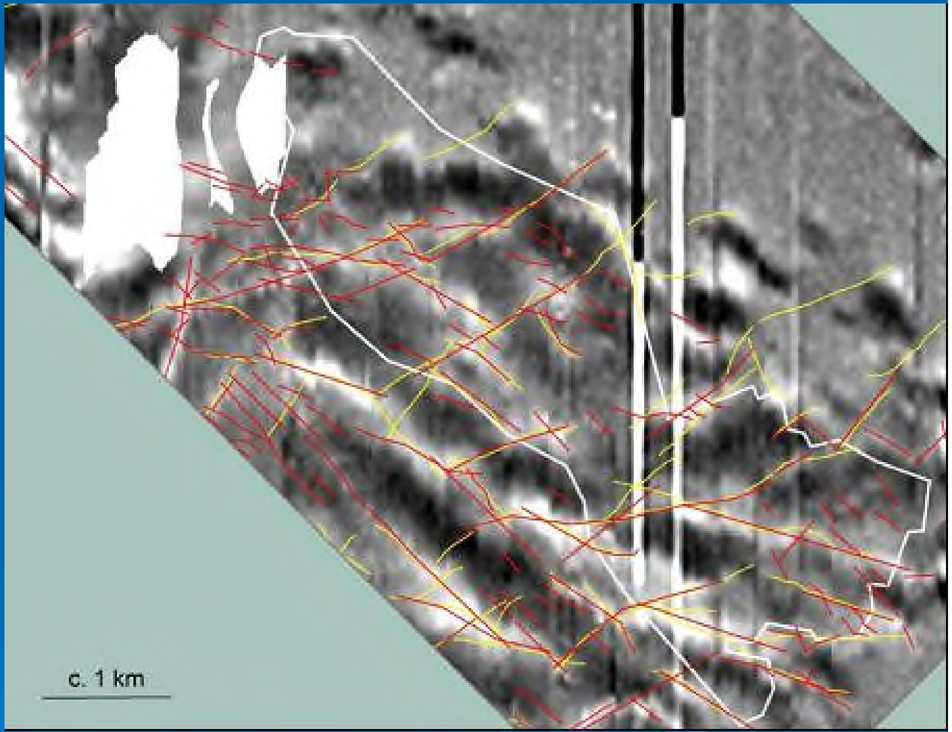
- GeoVista's longer indentified lineaments are likely due to a larger regional study area, and vice versa for GTK.

Case Study 2 (cont.)

- Interpretation from EM data overlaid on grayscale apparent resistivity (800Hz) map:



- Interpretation from VLF data overlaid on grayscale presentation of VLF total field ortho station data:



- Both GeoVista and GTK reported high levels of uncertainty (as much as 89%) in their interpretation of the EM and VLF data sources. Remarkably though, if identified lineaments less than 1km are removed then most of the lineaments correspond.

Case Study 2 (cont.)

- While both groups that performed interpretations assessed the uncertainty (the degree of clarity) of the lineament, the results indicate that they also from time to time seem to have considered whether a feature actually represented something or not, despite the data. A different degree of insight into the local geology may have led to different judgements.
- The length of a lineament, which is of critical importance, is difficult to define and there are no truly objective criteria to tell when two lineaments should be linked or kept separate. Length and linking of lineaments is also scale dependent.
- In spite of all the issues, GTK's interpretation does not show any major discrepancies when compared to GeoVista. The exceptions must be seriously taken into consideration

Case Study 2 (cont.)

- The comparison of the independent lineament interpretations compiled from multiple data sources has revealed that the results are, in majority, reproducible. Agreement of the interpretation is estimated at approximately 80 percent. The discrepancies however may not be insignificant and should be evaluated.

- Analysis based on a single attribute, or a combination of attributes as a stand-alone criterion for assessment can be seriously misleading.

Case Study 3

- In the third case study an investigation of value of lineament trace analysis for assessing groundwater availability was performed for Georgetown, Maine (Mabee, 1992). Initially a lineament trace analysis was performed independently by three people utilizing the same data sets, side-looking airborne radar (SLAR) and aerial photography.

- Comparison of the results of the Georgetown lineament trace analysis indicated low reproducibility with less than 45 percent agreement of the identified.

- Note that this is better than the 20 percent agreement in the first case study, but not nearly as good as the second case study. This appears to correlate reproducibility with multiple data sources.

Case Study 3 (cont.)

- However the investigation of the Georgetown lineament trace analysis also revealed that there was a good correlation between well productivity and proximity to a lineament, but only if the identified lineaments were limited to certain domains such as the predominant trends and overlap with the regional geologic orientation.

- If the identified lineaments were not limited to specific domains, analyzed, and validated then there was no correlation between well productivity and proximity to a lineament.

Addressing the Issues

- What can be learned from the case studies and how do we address the issues?
- With fewer data sources for analysis there is less repeatability.
  - With one data source repeatability was ~20 percent (Case 1)
  - With two data sources repeatability was ~45 percent (Case 3)
  - With numerous data sources repeatability was ~80 percent (Case 2)
- Filtering the identified lineaments within specific domains, such as regional geologic orientation, relation to geologic and topographic features, predominant azimuthal trends, length, continuity, density, et cetera reduce the likelihood of mistakenly identifying non-geological lineament as fractures, and improve reproducibility.

Addressing the Issues (cont.)

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- Performing independent validation of each source of analysis prior to combining the results means that the methodology and information unique to each analysis source does not get trivialized by the bulk of the overall data.

- Depending on the application, such as an environmental investigation, it may be critical to have a separate look at the significance of those lineaments that are excluded. Though we have established that most of the lineaments excluded through this process are non-geological in nature.

Addressing the Issues (cont.)

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- Multiple Analysis Sources with Independent Validation (MASIV) is a methodology that implements the points just discussed through an analytical process. It involves:

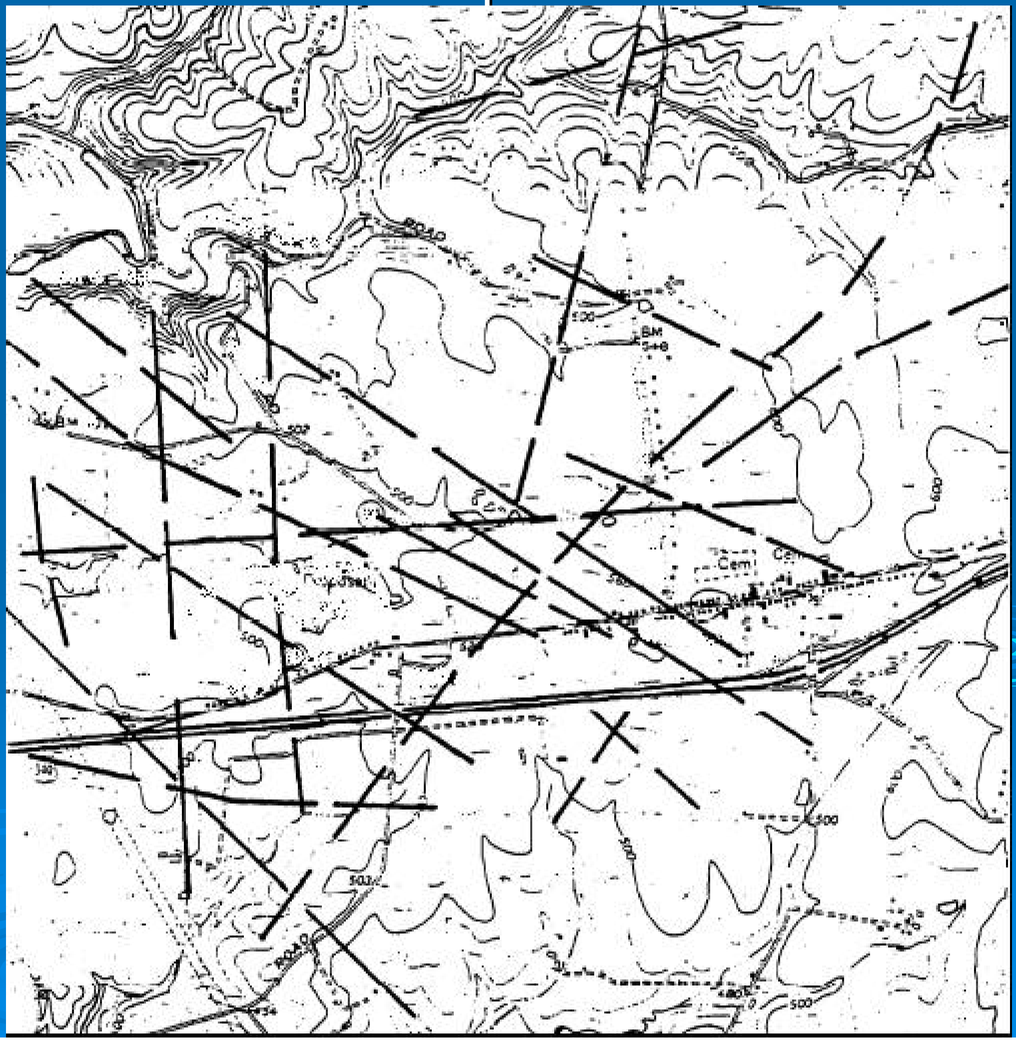
- Selection of multiple (3 or more) sources of data for analysis that is appropriate to the scale of investigation.

- Analysis of the multiple sources independently, and then statistical and spatial evaluation within defined domains to help validate the results.

- Combining the results into a single representation appropriate to the scale, with information about specific domains which can be used to more reliably interpret the analysis, and reproduce the results if needed.

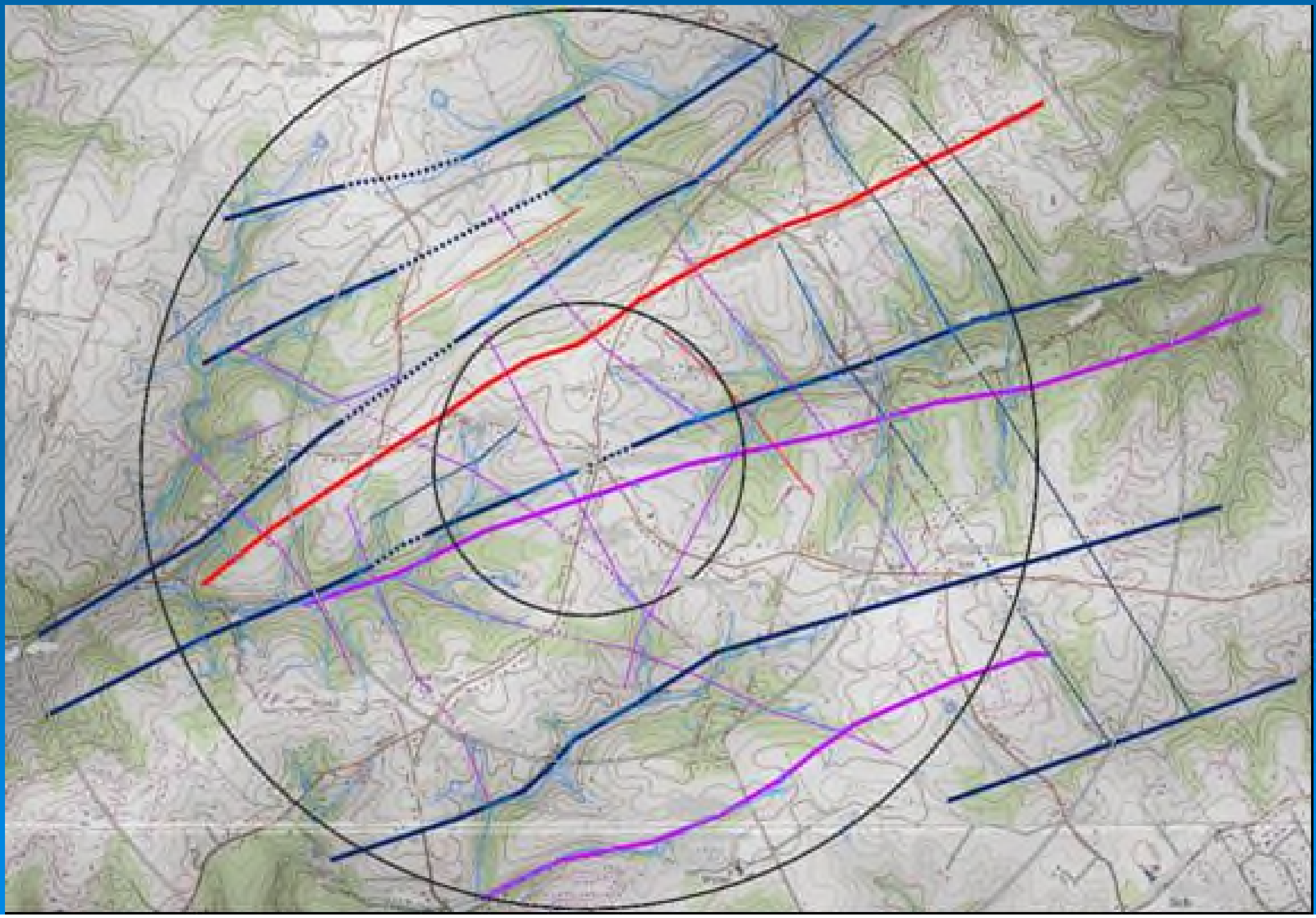
Examples

- Here are a few examples of local fracture trace analyses and a description of how the method used compares with the MASIV method. The examples presented progress from dissimilar to similar in comparison with the MASIV method.
- Frederick County Figure – Analysis performed for water supply assessment.
- One data source (Historic Aerial Stereography), One domains evaluated (Topography), The only information on the figure about domains that might aid interpretation is topography.



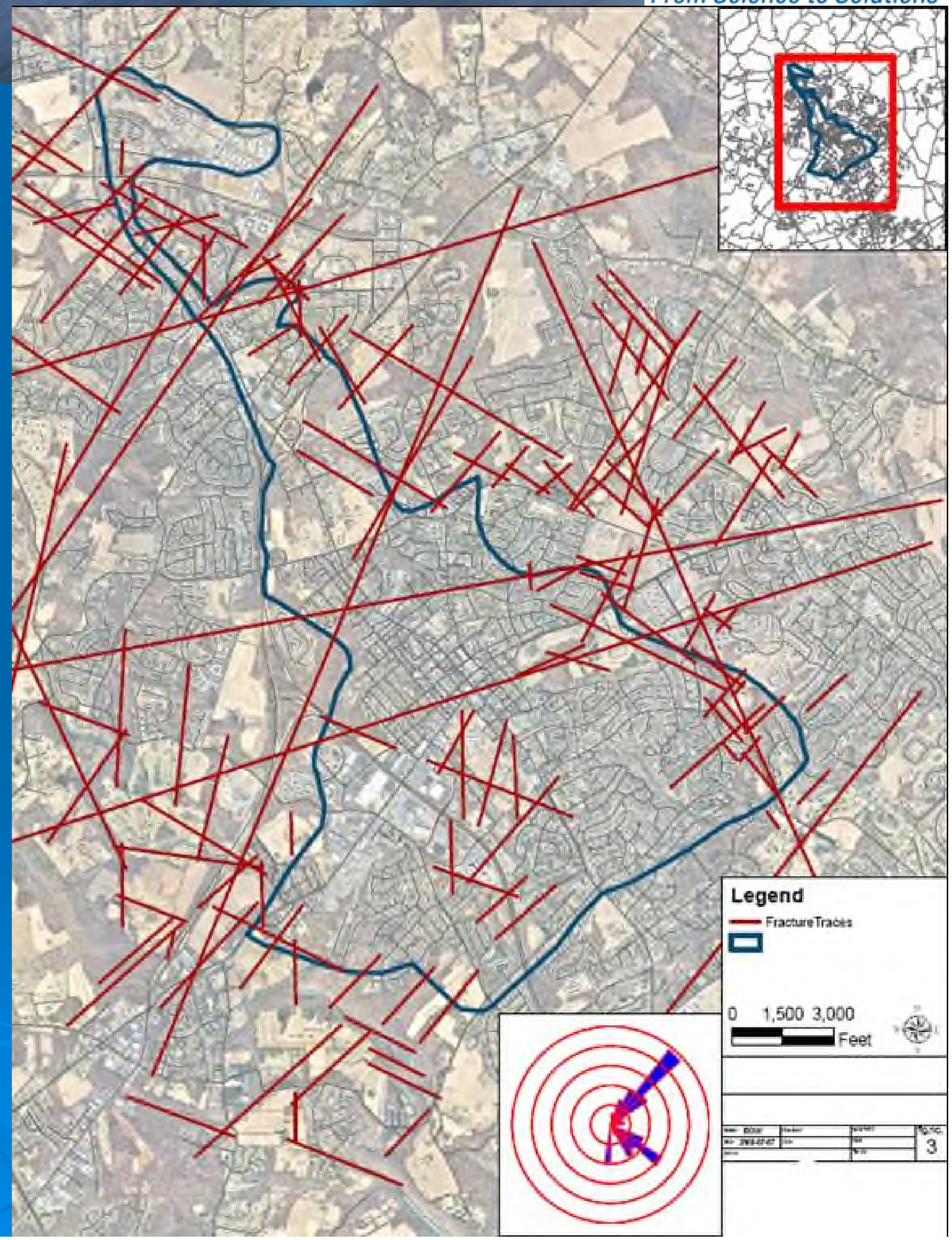
Examples (cont.)

- Baltimore County Figure – Analysis performed for an environmental assessment.
- Two data sources (LiDAR & Aerial Imagery), Four domains evaluated (Overlap with regional geologic orientation, length, continuity, & relation to topography), No information on the figure about the domains evaluated other than identification and topography that might aid interpretation.



Examples (cont.)

- Harford County Figure – Analysis performed for water supply assessment.
- Four data sources (LiDAR, High Resolution Aerials, Historic Aerial Stereography, & Aeroradioactivity)
- Six domains evaluated (Overlap with regional geologic orientation, Geology, Topography, Predominant Azimuthal Trends, Continuity & Length),
  A rose diagram is shown on the figure showing the azimuthal distribution of identified features.
- Other figures in the report related the fractures to topography, geology, and aeroradioactivity, in addition to aerials.



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The End

Thank You

Questions / Comments ?